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Technical Memorandum for the Conversion Technologies Life Cycle Assessment

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Submitted to

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Assembly Bill 2770 (Chapter 740, Statutes of 2002) requires the California Integrated Waste Management Board (CIWMB) to prepare a report on new and emerging technologies to convert organic wastes to usable energy and products, collectively referred to as "conversion technologies." This report must include a description and evaluation of the life cycle environmental and public health impacts of conversion technologies (CTs) as compared to existing municipal solid waste (MSW) management practices.

This memorandum describes the technical approach to be used in completing the LCA and is organized in the following manner:

- LCA Background
- General LCA Approach for Conversion Technology Systems
- Definition of LCA Goals and Scope Definition
- Inventory
- Impact assessment
- Interpretation
- Tasks, deliverables, and schedule

1.0 LCA Background and Application to Conversion Technology Systems

LCA is an approach for assessing the environmental and human health impacts associated with a product, technology, or system through the following phases:

- **Goal and Scope Definition:** defining the purpose, intended application, and intended audience for the LCA as well as the depth and breadth of the analysis and the level of detail that is required to meet the stated goals;
- **Inventory Analysis:** compiling the inputs and outputs across the entire life (i.e., cradle-to-grave) of the system;
- **Impact Assessment:** assessing the potential impacts of the inventory inputs and outputs to the environment and human health;
- **Interpretation:** evaluating the results of the inventory analysis and impact assessment in the context of the study goals and objectives.

The defining feature of an LCA is that it captures multi-media environmental and human health impact associated with all upstream and downstream stages of a system. This feature enables analysts to assess not only the total environmental and human health profile of a system, but also to identify where impacts may be shifted to one life cycle stage to another or from one media to another. Life cycle approaches shift environmental management from traditional "end-of-pipe" or "gate-to-gate" approaches to a more proactive and preventive approach.

1.1 LCA Standards

The life cycle concept and more formal LCA have evolved through an increasing awareness that a comprehensive view of production systems leads to environmentally friendly design and decisionmaking. The process for conducting an LCA has been recently been standardized by the International Standards Organization (ISO) and provides a useful framework and methodology for estimating and comparing the environmental performance of systems. The following ISO standards are available:

- ISO 14040: Environmental Management – Life Cycle Assessment – Principles and Framework (1997);
- ISO 14041: Environmental Management – Life Cycle Assessment – Goal and Scope Definition and Inventory Analysis (1998);
- ISO 14042: Environmental Management – Life Cycle Assessment – Life Cycle Impact Assessment (2000);
- ISO 14043: Environmental Management – Life Cycle Assessment – Life Cycle Interpretation (2000);

Although these standards provide requirements and recommendations in terms of what an LCA should include, they recognize that the actual methods used and level of detail employed in the assessment will vary by study. In general, the goals of the LCA will drive the level of complexity and detail required in the study. The most rigorous level of detail is required for cross-product comparative assessments.

1.2 General Approach for Applying LCA to Conversion Technology Systems

LCA will be applied to assess the environmental performance of CTs and compare them to existing MSW management practices in California. Our general approach is to develop LCA modules for CT systems and utilize RTI's Municipal Solid Waste Decision Support Tool (MSW DST) to capture the other life cycle components. These other components include waste management (collection, transfer, materials recovery, compost, combustion, landfill), energy production, transportation, and materials production activities. The data and models in the MSW DST have been developed for the US EPA during the past 10 years and have been extensively peer and QA reviewed. Using those general decisions and assumptions as a starting point, we will define boundaries, LCI items, and impacts that are specific to conversion technologies but yet consistent with those defined for the overall waste management system in the MSW DST. In addition, by using the MSW DST to capture the non-CT components of the system, we are able to place more emphasis on defining CT processes and collecting necessary data.

Information about RTI's MSW DST is provided in Attachment A.

2.0 Goals and Scope Definition

The goal and scope definition phase of the LCA is crucial for designing a study that is meaningful and useful for decisionmaking. The goals, approach, and methodology for the LCA of CT systems have been defined using our knowledge and experience with LCA and MSW systems and refined based on comments from the focus group meeting, peer review, and subsequent discussions with CIWMB. This section includes a summary of goal and scope definition components that are to be defined according to ISO 14040.

2.1 Goals of the LCA

The ***overall goal*** of the LCA is to estimate the impacts CTs have on the environment and public health. In general, the LCA will seek to answer questions in two categories:

1) What are the environmental and public health impacts of CTs?

2) How do the environmental and public health impacts of CTs compare to existing MSW management practices (e.g., recycling, composting, landfill)?

The goal is not necessarily to make definitive conclusions about CTs or the environmental preference of CTs compared to existing MSW management options. Rather, the goal is to better understand the potential environmental and human health impacts that may result from the commercialization of CTs, as well as the tradeoffs of employing CTs as alternatives to existing MSW management practices.

The LCA is being carried out by mandate of Assembly Bill 2770 (Chapter 740, Statutes of 2002) that requires the CIWMB to conduct an environmental, human health, and market impact assessment of CT systems. The CIWMB specified in its Request for Proposals that the approach to be used to assessment the environmental and human health impacts be LCA. The intended audience for this study is the State of California policymakers as well as State and local solid waste planners and decisionmakers.

2.2 System Function and Functional Unit for the LCA

The ***function*** of a CT system is to transform MSW or specific components of MSW into energy and useful products (e.g, chemical feedstocks). The ***functional unit*** is the management of a given quantity and composition of MSW defined by the region under study. For example, the functional unit of the LCA could be the management of 3,550 tons per day of organic waste in the San Francisco region.

2.3 Conversion Technology Systems to be Studied

CT systems that were identified in the Request for Proposals by the CIWMB included gasification, distillation, acid hydrolysis, enzymatic hydrolysis, plasma arc, and catalytic cracking. Of these systems, the CIWMB specified that initial LCA scenarios should be based on the following technologies:

- acid hydrolysis,
- catalytic cracking, and
- gasification

Each of these technologies is described briefly below.

<u>Acid hydrolysis</u> involves using a concentrated acid (typically sulfuric) to break down the lignocellulosic fraction of MSW to sugars. A fermentation step converts these sugars to ethanol. Except in the case of strong hydrochloric acid hydrolysis, acid hydrolysis is usually conducted at

elevated temperatures (100 to 240°C) for various lengths of time. At higher acid concentrations, it can be carried out at temperatures as low as 30°C.

Catalytic cracking can be used to recover hydrocarbon products from MSW plastics. In catalytic cracking, a catalyst, such as a zeolite, is used to break down polymers into monomers. There are seven types of polymers that account for more than 90% of total plastic wastes: polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polyurethanes (PU) and poly-amides (PA). Based on current chemical prices, monomers would be the most valuable products derived from poly(ethylene), poly(propylene), and poly(styrene). Unfortunately, with the exception of poly(styrene), monomers are difficult to obtain in large yields by thermal or catalytic cracking of these polymers. Therefore, one goal of research is to find catalytic cracking conditions under which polymers are efficiently converted to C_2-C_6 hydrocarbons, because these substances are used in industry in large quantities and constitute high value products.

Gasification is used to produce fuel gas from waste. Gasification occurs when thermal decomposition takes place in the presence of a small amount of oxygen or air. Gasification produces a combustible gas mixture primarily containing methane, complex hydrocarbons, carbon monoxide, and hydrogen. The combustible gas mixture can then be burned in boilers, or cleaned for combustion in gas turbines. The State of California has a very specific legislative definition (California's Public Resources Code 40117) of gasification that requires:

a) The technology does not use air or oxygen in the process, except ambient air to maintain temperature control.
b) The technology produces no discharges of air contaminants or emissions, including greenhouse gases.
c) The technology produces no discharges to surface or groundwaters.
d) The technology produces no hazardous waste.
e) To the maximum extent feasible, the technology removes all recyclable materials and marketable green waste compostable materials from the solid waste stream prior to the conversion process and the owner or operator of the facility certifies that those materials will be recycled or composted.
f) The facility where the technology is used is in compliance with all applicable laws, regulations, and ordinances.
g) The facility certifies to the CIWMB that any local agency sending solid waste to the facility is in compliance with this division and has reduced, recycled, or composted solid waste to the maximum extent feasible, and the board makes a finding that the local agency has diverted at least 30 percent of all solid waste through source reduction, recycling, and composting.

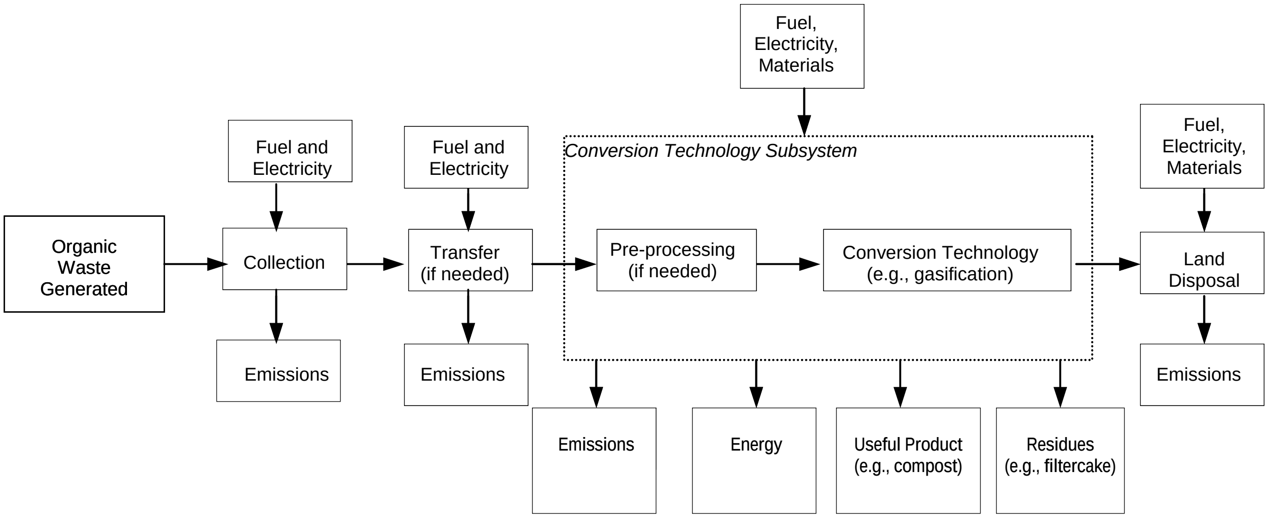


Figure 1. General Life Cycle Boundaries for a CT System.

From these three technologies, specific process designs will be identified and verified against the project goals to ensure they will provide the desired outcome. That is, the chosen technology designs need to be suitable for the feedstock, waste management scenarios, and sites under investigation. The University of California at Riverside (who is doing work under a separate contract for CIWMB to characterize CTs) is currently evaluating different technologies for their feasibility for immediate commercialization in California. RTI and its subcontractor NREL will work with the University to identify and define specific CT process designs that meet the needs of this study.

2.4 General System Boundaries

Figure 1 illustrates the overall life cycle system boundaries for a CT system. In the figure, the boundaries include not only the CT and other MSW management operations but also processes that supply inputs to those operations such as fuels, electricity, and materials production. Likewise, any useful energy or products produced from the CT system are included.

Once the specific CT designs have been identified based on the technical evaluation of CTs being performed by the University of California and NREL, we will develop detailed process descriptions and prepare process flow diagrams to identify mass flows, energy consumption, environmental releases, and other significant waste production and resource utilization parameters. An important aspect of this step is identifying the key aspects (e.g., facility construction and operation parameters) of each process that need to be considered and ensuring that all CT systems are defined in a consistent manner. For example, if one CT system description includes the production of materials used for pollution control, then all CT system descriptions should include this aspect. In the case of defining the CTs, it is also critical to highlight any waste preprocessing steps (e.g., separation, shredding, etc.) that may be required.

The system boundaries would be largely based on the mass flow of materials and energy in and out of the different unit processes included in the system. The collection, transfer, and residue disposal steps can be modeled so that they are held constant for all technologies evaluated, unless the technology requires a special process to replace of these. The CT and any necessary pre-processing steps can then be modeled independently and added to the collection, transfer, and disposal processes. System parameters (such as waste composition or energy output) could be varied during model runs to investigate sensitivity of emissions to these system parameters.

The main categories of inputs and outputs that will be compiled for each CT system are consistent with those that RTI includes in its MSW DST and include annual estimates for energy consumption, air emissions, water pollutants, and solid waste. A specific, but preliminary listing of input and output parameters is included in Section 3.1. In deciding upon which parameters to include in the analysis of CTs, our goal is to identify all relevant inputs and outputs. Therefore, some of the parameters included in Section 3.1 may not be relevant to CTs and there may be some additional parameters added if found to be relevant to a particular CT.

In comparing CTs to existing MSW management practices, we need to have consistent data for each parameter (e.g., dioxin/furans) across all unit processes in the waste management system. Therefore, if data for any given parameter is not consistently available across all processes included in the system, then the parameter will not be included in the comparative results of CTs to existing management practices. However, parameters for which we have data, but not consistent data across all processes, will be included in the LCA report when describing specific CTs.

2.5 Allocation Procedures

The design of the CT module will be such that the LCI coefficients are allocated to the total mass and composition of waste input. This approach is consistent with the other process modules of the MSW DST and will allow for component-specific (e.g., newsprint versus yard waste) analysis. Possible bases for allocation could include mass, volume, energy, or stoichiometric equations to tie elemental properties to emissions.

As the specific CT systems are identified for inclusion, we will review their processes and determine the appropriate method to allocate energy and emissions. With respect to allocation issues likely to be particularly difficult and therefore controversial, we will work with key internal and external contacts to achieve the best possible approaches.

2.6 Types of Impacts to Consider and Impact Assessment Methods

In general, we are focusing on impacts to the environment and human health as specified in the Request for Proposals, which are detailed in Section 4. Because LCA is iterative in nature, we will start from this list of impacts and as research progresses on the various CTs, we may learn about different or additional impacts that merit inclusion. We will define the final impacts (e.g., acidification) considered and desired impact indicators (e.g., acid equivalent potential) that will be used to evaluate CTs. These same impacts and impact indicators will also applied to existing waste management practices.

2.7 Data Quality Goals and Assessment

No primary data collection activities are planned for this study. We will rely on secondary data sources only. From secondary sources, we will seek data that is high quality, objective, well documented, and has been critically reviewed and/or verified. Our goal is to have quality, scientifically based data for each CT. Our focus will be on collecting data that is based on actual commercial-scale CT operations, California-specific infrastructure, and specific CT facility designs.

We will follow the ISO 14040 (1997a, 1997b) guidelines for assessing and reporting data quality for the following quality aspects:

- time-related coverage,
- geographical coverage,
- technology coverage,
- precision,
- completeness,
- representativeness,
- consistency, and
- reproducibility.

2.8 Assumptions and Limitations

All key assumptions and limitations of the LCA will be carefully documented and presented in the final report. Assumptions and limitations will evolve as the LCA progresses and might include such aspects as:

- CT facility design specifications
- Feedstock requirements and availability
- Base and future year CT system scenarios
- Selection of inventory items and impacts
- Use of average, proxy or surrogate data
- Inventory and impact assessment model assumptions
- Assumptions and limitations in interpreting LCA results

2.9 Critical Review

In general, critical reviews of LCAs are optional and typically based on the purpose and intended applications of the study. Only for LCAs that are used to make comparative assertions is critical review required. For this study, where we will ultimately be comparing the environmental impacts of CTs versus existing MSW management practices, critical review is needed to ensure that the technical approach, methods, data, and results adequately satisfy the requirements of the study.

Multiple levels of critical review have been built into this study, including:

- Focus group review of technical approach
- Peer review of technical approach
- Board review of technical approach
- Internal review of results
- Public workshop
- Peer review of results
- Board review of results

Comments from each level of review will be summarized and responses and recommended modifications to the study prepared by the project team.

3.0 Life Cycle Inventory Analysis

The purpose of the life cycle inventory analysis (LCI) is to collect data and develop calculation procedures to quantify the relevant inputs and outputs of a system. The process of conducting an LCI is iterative in that, as data are collected and more is learned about the system, new data requirements or limitations may be identified that necessitate redrawing of system boundaries, a change in data collection procedures, or modification of study goals and scope.

The LCI and data collection effort will reflect the system boundaries and detailed CT process descriptions. Where available, data on the effect of perturbations of the base system design (variations in feedstock composition etc.) and performance will also be collected to facilitate sensitivity and statistical analysis. In cases where specific data are not available from a vendor or for a particular feedstock or waste fraction, modeling or representative data may be used.

3.1 LCI Data Collection Goals

The goal of our data collection effort is to ensure that appropriate data are collected to support the LCI and impact assessment phases of the LCA. Through previous work conducted by RTI, extensive life cycle data have already been collected or developed for waste management processes and are available for use in this study. RTI's existing data include energy consumption, air emissions, water effluents, and solid waste for waste collection, transfer stations, materials recovery facilities, yard and mixed municipal waste composting, waste-to-energy combustion, landfill disposal, and supporting life cycle operations of electrical energy production (using national, regional, or user-defined grids), fuels production (e.g, diesel fuel), virgin and recycled materials productions (e.g., glass containers), and transportation (e.g., over-road haul). RTI's data have been carefully documented to ensure transparency and thoroughly peer reviewed and, most importantly, will allow us to focus on collecting or developing comparable data for CTs.

We plan to focus LCI data development efforts on the parameters listed in Table 1 as a starting point. As more is learned about specific CT systems and their inputs and outputs, we may add parameters to capture significant releases (e.g., air toxics) or remove parameters that are not relevant to any technology.

3.2 LCI Data Collection Approach

Based on the CT system boundaries, data will be collected, reviewed, and compiled for each technology. We will work with the internal and external contacts to identify and collect available data for each of the CTs. These data will be used to develop emission/energy factors and cost functions for use in conducting the LCI and possibly for the market impact assessment. Data will be collected from the following types of sources:

- Publicly available literature
- Federal reports
- State and municipal governments
- Industry reports
- Trade associations
- Waste collection, processing, and disposal facility records and reports
- Previous studies (e.g., NREL biogas study, etc.)
- LCA practitioners.

RTI recently conducted a literature review for CIWMB (RTI, 2002) to identify potential sources of life cycle data for conversion technologies and only limited data were found. As part of this study, we will devise an approach for collecting or developing the necessary data. This approach may include, but is not limited to, expanding the Web and literature review to include international sources, contacting technology vendors, developing data from surrogate sources. An annotated bibliography of potential data sources from RTI's preliminary literature review is included as Attachment A.

For a number of activities (e.g., front-end loader operation) or materials (e.g., lime for pollution control), we are able to use data developed as part of the MSW DST. In addition, extensive modeling of biofuel and biopower systems has been conducted by NREL. These models or other data obtained during their development may be used when specific data for a feedstock and conversion technology are not available.

Table 1. LCI Parameters To Be Used As A Starting Point.

Energy	Air Emissions	Water Pollutants	Solid Waste
Embodied Energy	Acetaldehyde	Acid	Residual waste
Consumption (by type)	Acreolin	Ammonia	Ancillary process waste
Production (by type)	Ammonia	Arsenic	
	Antimony	BOD	
	Arsenic	Boron	
	Barium	Cadmium	
	Benzene	Calcium	
	Beryllium	Chlorides	
	Cadmium	Chromates	
	Carbon Monoxide	Chromium	
	Carbon Tetrachloride	COD	
	Chlorine	Copper	
	Chromium	Cyanide	
	Carbon Dioxide (biomass)	Dissolved Solids	
	Carbon Dioxide (fossil)	Fluorides	
	Cobalt	Iron	
	Dioxins/Furans	Lead	
	Formaldehyde	Manganese	
	Hydrocarbons	Mercury	
	Hydrochloric acid	Metal Ion	
	Hydrogen Flouride	Nitrates	
	Iron	Oil	
	Kerosene	Other Organics	
	Lead	Phenol	
	Manganese	Phosphate	
	Mercury	Selenium	
	Methane	Sodium	
	Methylene Chloride	Sulfuric Acid	
	Naphthalene	Suspended Solids	
	Nickel	Zinc	
	Nitrogen Oxides		
	Nitrous Oxide		
	N-nitrodimethylamine		
	Other Aldehydes		
	Other Metals		
	Other Organics		
	Particulate		
	Perchloroethylene		
	Phenols		
	Potassium		
	Rubidium		
	Selenium		
	Sodium		
	Sulfur Oxides		
	Trichloroethylene		
	Zinc		

In compiling data, emphasis will be placed on identifying the best available data in terms of quality, completeness, and documentation. Where data are not available, applicable surrogate data will be used and these data will become a part of the parameter variation study.

3.3 Summarize LCI Data Collected and Assess Data Quality

Available data will be summarized for each CT. This summary will provide insight into extent of coverage that can be achieved by the available data and any data deficiencies. We will apply some preliminary sensitivity analyses to identify areas for improving data quality or collecting additional data. Data sources and quality will also be evaluated and tracked. We will follow the ISO 14040 guidelines for assessing and reporting data quality for the following quality aspects:

- time-related coverage,
- geographical coverage,
- technology coverage,
- precision,
- completeness,
- representativeness,
- consistency, and
- reproducibility.

As part of the process of summarizing the available data and its quality, we will also document any assumptions employed and limitations in using the data for the LCI.

3.4 Describe Variations in LCI Parameters

As the data collection progresses, two types of process parameters will be missing or uncertain parameters, and parameters that are by nature variable (e.g., feedstock composition). These parameters will be slated for sensitivity analysis. There are two types of analysis that could be utilized: single point sensitivity analysis to determine the possible range of effect of uncertain data and process parameters that are variable by nature (e.g., feedstock composition) and, where possible, Monte Carlo analysis to determine the most likely outcome and its effect on cost, energy, and other factors.

3.5 Develop LCI Module for CT Systems

To calculate the LCI coefficients for CTs, LCI "process modules" will be developed for each CT type (e.g., gasification). The process module will be a spreadsheet model (MS Excel) that includes equations that utilize design information for conversion technology options to generate LCI coefficients. The design of the CT module will be such that the LCI coefficients are allocated to the total mass and composition of waste input. This approach is consistent with the other process modules of the MSW DST and will allow for component-specific (e.g., newsprint versus grass clippings) analysis. Possible allocations methods might include mass, volume, or energy. With respect to issues likely to be particularly difficult and therefore controversial, such as allocation methodologies, we will work with key internal and external contacts to achieve the best possible approaches.

3.6 Conduct LCI for CT Scenarios

LCI results will be generated for predefined waste management scenarios incorporating various CT systems. In analyzing waste CTs, one wants to know (1) how the technologies compare to more traditional waste management practices, and (2) how the technologies compare to one another. The RTI MSW DST and the CT LCI module will be used to conduct the scenario analyses. For the CT scenarios, CIWMB defined the following system designs as being desired for preliminary analysis.

2003 Base Year

- Two to three acid hydrolysis facilities in each of the San Francisco Bay Area and the greater Los Angeles regions, with capacity totaling 1,500 tons per day in each region, that produce ethanol and that are located at landfills or materials recovery facilities (MRFs)
- Three to four gasification facilities in each of the two regions, with capacity totaling 2,000 tons per day in each region, that produce electricity and that are located at landfills or material recovery facilities
- One stand-alone 50 ton per day catalytic cracking facility in each area that converts unrecyclable plastic resins to diesel.

Years 2005 to 2010

- One additional gasification plant built in each region in the year 2005
- Two additional acid hydrolysis plants built in each region in 2007
- One additional gasification plant built in each region in 2010.

The three particular conversion technologies (acid hydrolysis, catalytic cracking, and gasification) and the capacity assumptions in the scenarios were chosen because these were the technologies and capacities in which local jurisdictions in California have shown particular interest as evidenced by “Requests For Information” being issued. In addition, the three chosen technologies were seen as being commercial ready based on research conducted prior to issuance of the CIWMB’s Request for Proposals.

For purposes of LCI modeling, we will assume the greater Los Angeles region to be comprised of the counties of Los Angeles, Orange, Riverside, and San Bernardino. The San Francisco Bay Area is assumed to include the counties of Alameda, Contra Costa, San Francisco, San Mateo, Santa Clara, Solano, Marin, Napa, and Sonoma. CIWMB reviewed the assumptions made regarding the location of the facilities and the potential value of including a smaller region and a rural region with more agriculture wastes. As a large percentage of California’s municipal solid waste is generated and processed within the Los Angeles and San Francisco urban areas, CIWMB believes that the environmental impacts of CTs should be assessed within these same areas.

Based on our experience in conducting scenario analyses for waste management systems, it will be necessary to address the scenario designs after reviewing preliminary results and possibly develop additional scenarios to resolve specific issues (e.g., variations in rural versus urban communities, co-location of CTs with MRFs).

4.0 Life Cycle Impact Assessment

The LCIA component of LCA is designed to provide a set of environmental indicators for a system based on the results of the LCI. In this case, the system is a waste management system using a conversion technology versus other traditional approaches (e.g., recycling, composting, land disposal). An impact assessment can be done at a more qualitative or quantitative level depending on the goals and scope of the study. The impact assessment typically includes:

- Assigning LCI data to impact categories (classification)
- Modeling of the LCI data within impact categories (characterizing)
- Aggregating the results (weighting).

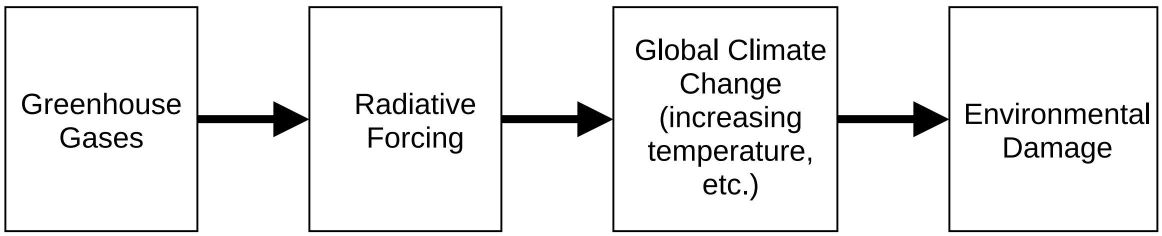
The LCI for the different CT scenarios analyzed will be used as inputs to the LCIA. RTI prepared (EPA, 1995) benchmark LCIA guidelines for EPA and was an active participant in a number of addition LCIA methodology and application studies (SETAC, 1997; EPA, 1999) and is familiar with ISO 14042 guidelines (ISO, 1998a) for environmentally relevant impact indicators. This section outlines our technical approach to conduct the LCIA.

4.1 Compile LCI Data by Impact Category and Scale of Impact

Data resulting from the scenarios analyzed in the LCI phase will be classified into the impact categories listed in Table 2. These categories are considered to meet ISO 14042 criteria for environmental relevance in a previous study (EPA, 1999). In conjunction with assigning LCI data to impact categories, the scale of impact will also be identified. This requires consideration of the impact category. For example, climate change is a global issue whereas photochemical smog is a local issue.

4.2 Characterize Impacts

To characterize impacts for defined impact categories, LCIA models have been developed that convert LCI results into impact indicators. An impact indicator is generally an intermediate node on the environmental mechanism for which there is a science-based correlation to the impact. For example, a global warming potential is quantified to evaluate the radiative forcing potential of the greenhouse gases released into the atmosphere because this measure integrates the forcing function on the earth's climate:



Example impact indicator models for different impact categories are listed in Table 2. Note that the impact categories and models included in Table 2 are for purposes of illustration and do not necessarily represent the impacts or models that will be used in the LCA of CTs. Our goal with respect to impact assessment is to identify all potential environmental and human health impacts associated with CTs and assess those impacts as appropriate. In cases where quantitative data and/or impact models are not available, the assessment will be qualitative. In cases where quantitative data and impact models are available, the assessment will be quantitative.

5.0 Life Cycle Interpretation

The interpretation phase of LCA is designed to bring together the results from the LCI and LCIA to reach conclusions and recommendations (ISO, 1998b). For this study, the interpretation would be directed at identifying significant issues related to CT systems, reporting on the quality of data and results, identifying key parameters that govern the LCA results for CTs, and presenting the findings of the scenarios analyzed in a format that is clear and understandable to the general public. The scenarios analyzed as part of this study and the model results will be clearly documented including a listing and explanation (where required) of all major variables and an analysis of the case results. Sensitivity ranges used will be documented and explained along with the results and implications of the cases. To the extent possible, policy implications of the model results will be assessed and reported along with input data changes that might impact these implications.

5.1 Identify Significant Issues

One of the objectives of conducting an LCA is to identify significant issues that might otherwise have been overlooked in evaluating the environmental performance of a process or system. To identify significant issues, we will compare and contrast the alternative waste management scenarios. Using the MSW DST, we are able to evaluate results by waste management process and by waste constituent and narrow in on activities and parameters that drive the results. We will then investigate those activities and parameters further by varying key inputs in an incremental manner and re-run the MSW DST to evaluate the impact on results.

Table 2. Example Life Cycle Impact Categories and Indicator Models

Impact Category	Impact Indicator Model	Indicators	Example of LCI Data Needed for Model
Global warming	Intergovernmental Panel on Climate Control	CO_2 equivalents	CO_2, NO_2, CH_4, CFCs, HCFCs, CH_3Br
Stratospheric ozone depletion	World Meteorological Organization	CFC-11 equivalents	CFCs, HCFCs, Halons, CH_3Br
Acidification	Chemical Equivalents	Acidification potential	SO_x,, NO_x, HCL, HF, NH_4
Photochemical smog	Empirical Kinetic Modeling Approach	Maximum incremental reactivity	NMHCs
Eutrophication	Redfield Ratio	PO_4 equivalents	PO_4, NO, NO_2, NH_4
Human health	EDF Scorecard	Toxicity equivalents	Toxic chemicals
Ecological health	RTI LCIA Expert Version 1	Toxicity, persistence, and bioaccumulation potential	Toxic chemicals
Resource depletion	LCSEA Model	Mass, volume, or land space consumed	Quantity of fossil fuels,volume of water, acres of land

5.2 Assess Quality of Data and Results

To use and communicate LCA results properly, it is important to understand the results and the underlying quality of the data used to generate those results. Data sources and quality will be evaluated, tracked, and documented. We will follow the ISO 14040 guidelines from assessing and reporting data quality for the following quality aspects, as possible: time-related coverage, geographical coverage, technology coverage, precision, completeness, representativeness, consistency, and reproducibility. We will also identify and document key assumptions and limitations surrounding the overall LCA results and provide guidance for use of the results in decisionmaking.

5.3 Evaluate and Identify Sensitive Parameters

An important part in understanding and applying the LCA and scenario results is to understand the key parameters that govern the LCA results for CTs. For example, as a general rule of thumb, if a process consumes a large amount of fuel to operate equipment then it may follow that fuel combustion emissions and related impacts are the most significant of the system. Due to the potentially large number of variables and constraints involved in developing the LCI module for CTs, it may not be possible to conduct a formal sensitivity analysis on the module or the LCA as a whole. Through past work in developing LCI for MSW systems, we have gained an understanding of what typically drives LCA results and can use that as a starting point to manually make incremental changes to parameters and evaluate the impact on LCI results.

5.4 Prepare Overall LCA Results

The results of LCA of CTs will be presented in tabular (spreadsheet) format, comparing to results of CTs systems to existing MSW management practices. From this table, charts and graphics could be easily generated to highlight desired aspects.

6.0 Proposed Report Outline

I. Background and Purpose
II. Goals and Scope
- a. Definition of Study Goal
- b. Description of Scope and Boundaries
- c. CT Process Descriptions

III. Life Cycle Inventory Analysis
- a. Data Sources
- b. Calculation Procedures
- c. Results from CT Scenarios

IV. Life Cycle Impact Assessment
- a. Methods
- b. Results based on the Inventory for CT Scenarios

V. Life Cycle Interpretation
- a. Interpretation of LCI and LCIA results
- b. Key Assumption and Limitations
- c. Data Quality Assessment

VI. Critical Review
- a. Name and Affiliation of Reviewers
- b. Critical Review Reports
- c. Responses to Review Comments

VII. References
VIII. Technical Appendices
- a. Detailed Life Cycle Inventory Results
- b. Details of Impact Assessment Methods
- c. MSW DST Information
- d. Other Technical Appendices (as needed)

7.0 References

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